## 1.0 Introduction

The U.S. Army Engineering and Support Center, Huntsville (USAESCH) is currently engaged in projects which require the disposal of uncovered/discarded ordnance and explosives (OE) on public and private lands. The uncovered OE item is often detonated in place if it is too dangerous to move. In some cases, covering and tamping with loose earth is used to contain the blast and fragments. Another method to mitigate the fragmentation and blast effects is to cover the item with sandbags. However, traditionally there has been no method to determine the optimum configuration or the required thickness of such a sandbag enclosure.

The Structural Branch, USAESCH, sponsored a test program in 1997 to evaluate the use of sandbag enclosures for fragment and blast mitigation, for intentional detonations at Ordnance and Explosives (OE) sites. Southwest Research Institute (SwRI), under contract to USAESCH, performed a two phase test program of sandbag enclosures. In phase one, the preliminary explosive test phase, four tests on a 155-mm projectile were performed to refine and optimize the test procedure. This test procedure was used in phase two, the comprehensive explosive test phase. In phase two, a total of fourteen tests with five different munitions were performed to determine the thickness of sandbags required to capture all primary fragments. Measurements were made of the overpressures at various places, sandbag throw distances, depth of fragment penetration, and noise levels. High-speed film cameras, video recorders and digital cameras were used to visually record the events.

The results of these tests have been used to develop guidelines for the use of sandbag enclosures. The guidelines include required sandbag thicknesses, configuration and construction of the sandbag enclosures, and withdrawal distances based on the greater of sandbag throw distances or 200 ft. This document provides a summary of the test results and these guidelines.

## 2.0 Test Program

### 2.1 Fragmentation Characteristics of Munitions

Prior to beginning this test program the fragmentation characteristics of a variety of munitions frequently encountered during OE site operations were determined. The fragmentation characteristics were calculated in accordance with procedures outlined in TM5-1300, “Structures to Resist the Effects of Accidental Explosions” [1] and detailed in CEHNC-ED-CS-S-98-1, “Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives” [2]. The fragmentation characteristics were used [redacted]

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# Use of Sandbags for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonation of Munitions

Prepared by
Joseph M. Serena, III, PE
Michelle Crull, PhD, PE

August 1998

Department of the Army
Huntsville Center, Corps of Engineers
Attn: CEHNC-ED-CS-S
P.O. Box 1600
Huntsville, AL 35807-4301
Telephone: Commercial 256-895-1650

Reviewed by: Wallace Watanabe 8/13/98
WALLACE WATANABE Date
Chief, Structural Branch

Reviewed by: Paul M. Lahoud
PAUL M. LAHOUD, PE Date
Chief, Civil-Structures Division

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD
2461 EISENHOWER AVENUE
ALEXANDRIA, VIRGINIA 22331-0600

DDESB-KO 23 February 1999

MEMORANDUM FOR DIRECTOR US ARMY TECHNICAL CENTER FOR EXPLOSIVES SAFETY (ATTENTION: SIOAC-ES)

SUBJECT: Use of Sandbags for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonations of Munitions, Report HNC-ED-CS-S-98-7 (August 1998)

References: (a) SIOAC-ESL memorandum, dated 30 Nov 98, same subject

(b) Joseph M. Serena and Michelle Crull, "Use of Sandbags for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonations of Munitions, Report HNC-ED-CS-S-98-7," (August 1998)

The subject site plan forwarded by reference (a) has been reviewed with respect to explosives safety criteria. The site plan addresses the use of sandbags, IAW reference (b) to mitigate hazards and protect personnel from intentional detonations of munitions up to the 155-mm M107. Based on the information furnished, the proposed use of sandbags for intentional detonations at ordnance and explosives (OE) sites, IAW reference (b) is approved.

A copy of this site plan package and this letter of approval must be available at OE sites where intentional detonations are conducted that use procedures of this siting package.

Point of contact is Dr. Chester E. Canada, DDESB-KT2 (PH: commercial: 703-325-1369, FAX: 703-325-6227, E-MAIL: canadce@hqda.army.mil).

Daniel T. Tompkins

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

cc:
Army Safety Office, ATTN: DACS-SF, Chief of Staff, 200 Army Pentagon, Washington, DC 20310-0200
Commander, U.S. Army Corps of Engineers, ATTN: CESO, 20 Massachusetts Avenue NW, Washington DC 20314-1000
Commander, U.S. Army Engineering and Support Center Huntsville, ATTN: CEHNC-ED-CS and CEHNC-OE-CX-Q, P.O. Box 1600, Huntsville, AL 35807-4301

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The results of these tests have been used to develop guidelines for the use of sandbag enclosures. The guidelines include required sandbag thicknesses, configuration and construction of the sandbag enclosures, and withdrawal distances based on the greater of sandbag throw distances or 200 ft. This document provides a summary of the test results and these guidelines.

## EXECUTIVE SUMMARY

The U.S. Army Engineering and Support Center, Huntsville (USAESCH) is currently engaged in projects which require the disposal of uncovered/discarded ordnance and explosives (OE) on public and private lands. The uncovered OE item is often detonated in place if it is too dangerous to move. In some cases, covering and tamping with loose earth is used to contain the blast and fragments. Another method to mitigate the fragmentation and blast effects is to cover the item with sandbags. However, traditionally there has been no method to determine the optimum configuration or the required thickness of such a sandbag enclosure.

The Structural Branch, USAESCH, sponsored a test program in 1997 to evaluate the use of sandbag enclosures for fragment and blast mitigation, for intentional detonations at Ordnance and Explosives (OE) sites. Southwest Research Institute (SwRI), under contract to USAESCH, performed a two phase test program of sandbag enclosures. In phase one, the preliminary explosive test phase, four tests on a 155-mm projectile were performed to refine and optimize the test procedure. This test procedure was used in phase two, the comprehensive explosive test phase. In phase two, a total of fourteen tests with five different munitions were performed to determine the thickness of sandbags required to capture all primary fragments. Measurements were made of the overpressures at various places, sandbag throw distances, depth of fragment penetration, and noise levels. High-speed film cameras, video recorders and digital cameras were used to visually record the events.

Required Wall and Roof Thicknesses for Sandbag Enclosures, with Expected Sandbag Throw Distances and Pressures, for Five Tested Munitions

| Munition | Charge Weight, Comp B, lb | Required Wall and Roof Sandbag Thickness, in | Expected Maximum Sandbag Throw Distance, ft | Expected Peak Pressure @ 40 feet, psi | Expected Peak Pressure @ 80 feet, psi | Expected Sound Level @ 100 feet, dB |
|---|---|---|---|---|---|---|
| 155-mm M107 | 15.4 | 36 | 220 | 0.18 | 0.09 | 115 |
| 4.2-in M329A2 | 8.17 (TNT) | 24 | 125 | 0.16 | 0.06 | 116 |
| 105-mm M1 | 5.08 | 24 | 135 | 0.18 | 0.08 | 120 |
| 81-mm M374A2 | 2.1 | 20 | 125 | 0.14 | 0.05 | 119 |
| 60-mm M49A3 | 0.43 | 12 | 25 | 0.08 | 0.03 | 118 |

US Army Corps
of Engineers
Engineering and Support
Center, Huntsville

# Use of Sandbags for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonation of Munitions

**HNC-ED-CS-S-98-7**
**AUGUST 1998**

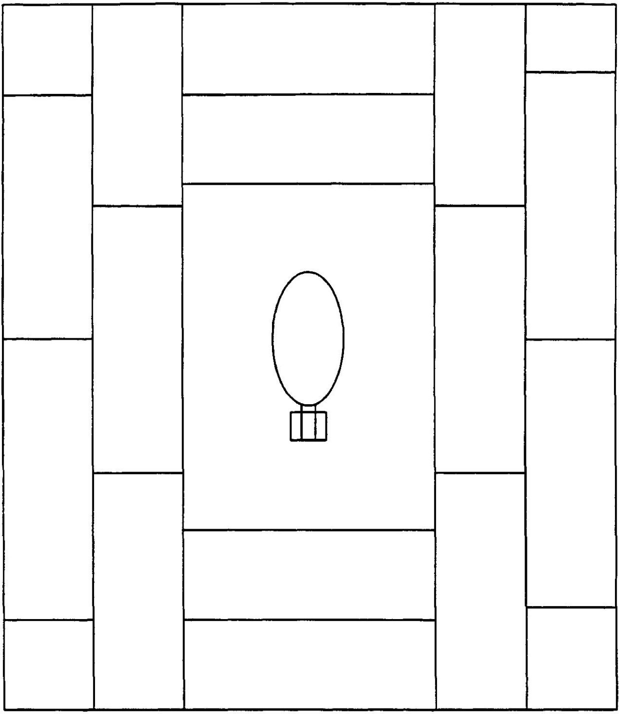


Figure 7 - Configuration for 12" Wall Enclosures

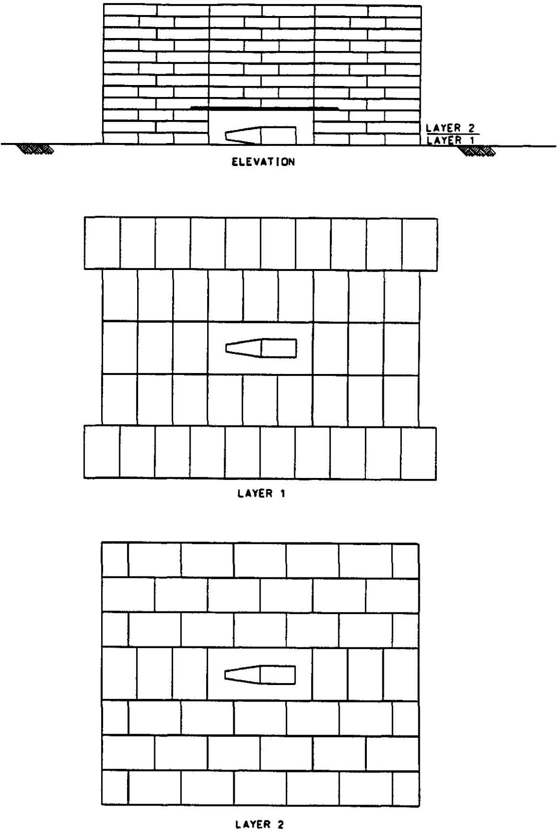
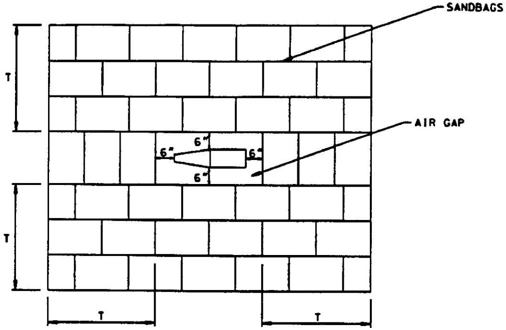


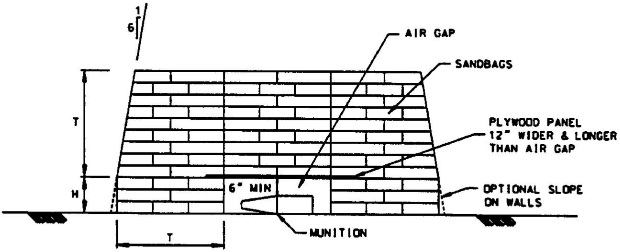

Figure 6 - Interlocking Alternate Layers of Sandbags

Figure 5 – Sandbag Enclosure for an 81 mm M374A2 mortar.




T=THICKNESS OF SANDBAGS REQUIRED FOR SPECIFIC MUNITION

PLAN VIEW AT ELEVATION H
SANDBAG ENCLOSURE




SIDE SECTION VIEW
SANDBAG ENCLOSURE

Figure 4 - Typical Sandbag Enclosure

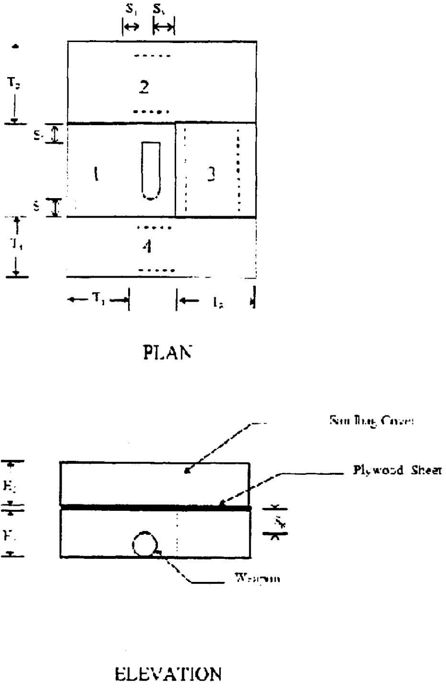
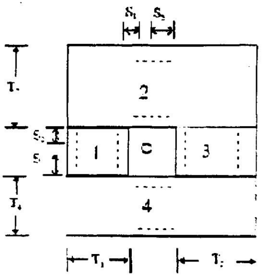
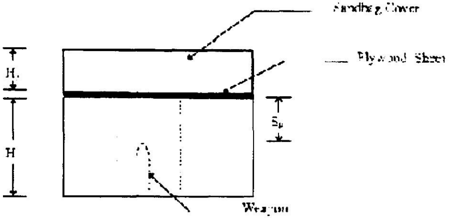



Figure 3 – Sandbag Enclosure Configuration for Horizontal Weapon Tests




PLAN




ELEVATION

Figure 2 – Sandbag Enclosure Configuration for Vertical Weapon Tests

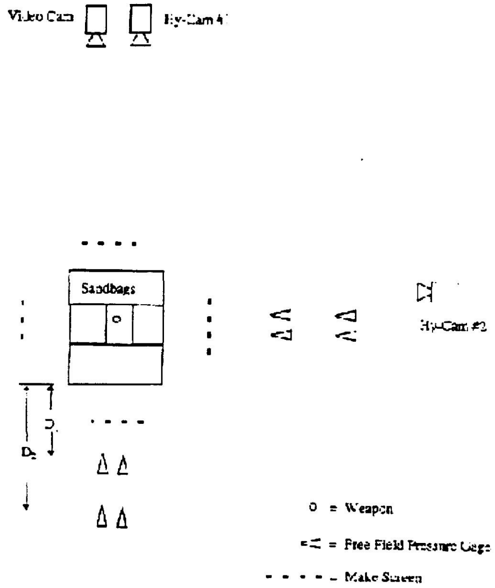



Figure 1 – Site Layout for Tests of Sandbag Enclosures

## 4.0 Summary and Conclusions

A test program has been performed to determine the effects of sandbag enclosures for mitigating fragments and blast effects due to an intentional detonation of a munition. A total of eighteen tests on five different munitions were performed. A summary of the test procedures and results are presented in this document.

The results of these tests have been used to develop guidelines for the use of sandbag enclosures to mitigate the fragments and blast effects due to an intentional detonation of a munition. Methods for determining the required sandbag thickness and the resulting sandbag throw distance are detailed in Section 3.0. Figures 4, 5, 6 and 7 show the resulting sandbag enclosures.

## 5.0 References


1. TM5-1300, "Structures to Resist the Effects of Accidental Explosions", Departments of the Army, the Navy, and the Air Force, November 1990.

2. HNC-ED-CS-S-98-1, "Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives", M. Crull, U.S. Army Engineering and Support Center, Huntsville, January 1998.

3. "Evaluation of Sandbags for Fragment and Blast Mitigation", D. Stevens, Southwest Research Institute, San Antonio, TX, January 1998.

4. "User's Guide for Microcomputer Programs CONWEP and FUNPRO Applications of TM 5-855-1. "Fundamentals of Protective Design For Conventional Weapons"", Revision 2, D. Hyde, US Army Corps of Engineers Waterways Experiment Station, February 1989.

Table 7 - Required Wall and Roof Thicknesses for Sandbag Enclosures, with Expected Sandbag Throw Distances and Pressures, for Tested and Non-Tested Munitions

| Munition | Charge Weight (lb) | $W_F$, Maximum Fragment Weight, lb | $V_F$, Initial Fragment Velocity, ft/s | Kinetic Energy, $10^6$ lb-ft$^2$/s$^2$ | Required Wall and Roof Sandbag Thickness, in | Expected Maximum Sandbag Throw Distance, ft | With-drawal Distance, ft |
|---|---|---|---|---|---|---|---|
| 155mm M107* | 15.48 | 0.467 | 4667 | 5.086 | 36 | 220 | 220 |
| 4.7-in Mark I | 6.07 | 0.591 | 3566 | 3.761 | 36 | 220 | 220 |
| 105mm M1* | 5.08 | 0.155 | 4870 | 1.840 | 24 | 135 | 200 |
| 4.2-in M329A2* | 8.165 | 0.079 | 6391 | 1.607 | 24 | 125 | 200 |
| 4-in Stokes | 7.92 | 0.078 | 6336 | 1.570 | 24 | 125 | 200 |
| 75mm M48 | 1.47 | 0.153 | 3471 | 0.922 | 24 | 125 | 200 |
| 3-in Stokes | 2.1 | 0.044 | 6189 | 0.835 | 24 | 125 | 200 |
| 2.75-in M229 Rocket | 4.8 | 0.050 | 5569 | 0.777 | 24 | 125 | 200 |
| 81mm M374* | 2.1 | 0.031 | 6721 | 0.696 | 20 | 125 | 200 |
| 37mm MK II | 0.53 | 0.030 | 5758 | 0.490 | 20 | 125 | 200 |
| 60mm M49A3* | 0.42 | 0.024 | 5114 | 0.310 | 12 | 25 | 200 |
| FMU 54A/B | 0.357 | 0.006 | 9031 | 0.263 | 12 | 25 | 200 |
| 40mm MK2 Mod 0 | 0.187 | 0.033 | 3605 | 0.215 | 12 | 25 | 200 |
| MK II Grenade | 0.125 | 0.014 | 3425 | 0.083 | 12 | 25 | 200 |
| 25mm M792 | 0.096 | 0.005 | 5736 | 0.081 | 12 | 25 | 200 |
| M67 Grenade | 0.40625 | 0.001 | 7006 | 0.029 | 12 | 25 | 200 |
| 20mm M56A4 | 0.0264 | 0.0000011 | 4941 | 0.004 | 12 | 25 | 200 |

* = tested munitions

### 3.3 Withdrawal Zone

A withdrawal zone is necessary for any detonation. This withdrawal zone applies to everyone, both public and operational personnel. The withdrawal zone is the maximum of the sandbag throw distance, the distance to a sound level of 140 db, or 200 ft. For all munitions tested, the sound level at 100 ft was substantially less than 140 db. At 200 ft. the sound level will be even lower. The withdrawal zones are also listed in Table 7.

Four walls of identical thickness should surround the munition. The minimum wall thickness should be the thickness determined using the procedure in Section 3.1 above. The sandbag walls should be stacked to maintain a clear standoff distance of 6 inches between the shell and the inside face of each wall. The interior face of each wall should be vertical but the exterior face can be built with a 1:6 slope (2" horizontal to 12" vertical). If a sloped outer face is used, the thickness of the wall, at the nominal "top" of the wall, 6 inches above the top of the munition, must be no less than the specified required thickness

The sandbags should be placed tightly against each other. All vertical joints should be staggered, so there is no clear line of sight from the munition to the exterior. As the wall is built, each new layer of sandbags should run in opposite direction to the layer below, so that the layers are interlocked (see Figure 6).

At a minimum, a double layer of sandbags shall be used. For example, when a 12" thickness is required, the sandbags should be oriented so that two sandbags are necessary to achieve this thickness (see Figure 7).

After the walls are constructed to a height of 6" above the upper surface of the munition, the shaped charge or other initiator should be placed on the shell. Ideally, the use of shaped charges, such as oil well perforators, is recommended. These add very little to the total charge weight for each detonation, given the highly directional nature of the effects of the shaped charge. Also, the use of shaped charges for initiation parallels test procedures. The shaped charge should be located either on top of the munition or on its side. If it is located on the side of the round, the charge should be tilted downward sufficiently to ensure that the shaped charge jet penetrates the round and is directed into the ground, rather than into the opposite sandbag wall. Generally, a small mound of sand next to the round can be used to establish this orientation.

A sheet of 3/4-inch thick Douglas Fir (or equivalent) plywood should be cut to the dimensions of the cavity between the walls, plus 12 inches in each direction. The plywood sheet is then centered on the walls so that it bears on 6" of each wall. The additional sandbags that make up the roof of the enclosure are then placed on top. As with the side walls, the roof sandbags should be stacked with staggered horizontal joints and alternating directions in each layer. The exterior sides of the roof may also be vertical or have a 1:6 slope. The thickness of the sandbag roof, above the plywood panel, must be the same as the required wall thickness.

After the sandbag layers of the roof have been placed to the correct height, the enclosure is complete and the munition may be detonated.

Table 6 - Maximum Fragment Weight, Initial Fragment Velocity and Kinetic Energy for Five Tested Munitions

| Munition | $W_F$, Maximum Fragment Weight, lb | $V_F$, Initial Fragment Velocity, ft/s | Kinetic Energy, $10^6$ lb-ft$^2$/s$^2$ |
|---|---|---|---|
| 155-mm M107 | 0.467 | 4667 | 5.085 |
| 4.2-in M329A2 | 0.079 | 6391 | 1.613 |
| 105-mm M1 | 0.155 | 4870 | 1.868 |
| 81-mm M374A2 | 0.031 | 6721 | 0.700 |
| 60-mm M49A3 | 0.033 | 3605 | 0.214 |

As an example, for a shell such as the 3-in Stokes Mortar Round, the maximum fragment weight and initial fragment velocity are 0.0436 lb and 6189 ft/s, respectively. The resulting kinetic energy is 0.835 x $10^6$ lb-ft$^2$/s$^2$. The next largest fragment kinetic energy in Table 6 is the 4.2-in M329A2 round. Therefore, a sandbag enclosure with a roof and wall thicknesses of 24 inches should be used to contain the fragments and suppress the blast overpressures. The maximum sandbag throw distance is 125 ft. Therefore, the withdrawal distance is 200 ft.

Based on this procedure, a more complete list of typical munitions is given in Table 7. This table includes the required sandbag wall and roof thicknesses and maximum expected sandbag throw distances to be used for each munition. For other munitions not listed in Table 7, the procedure given above can be used. The procedure should not be used to extrapolate sandbag thicknesses or sandbag throw distances for munitions larger than the 155-mm M107.

### 3.2 Enclosure Construction Method

The enclosure construction method follows the procedure that was used to build the test enclosures, with a few modifications. Figure 4 illustrates a typical enclosure. Figure 5 shows a photograph of a sandbag enclosure for an 81 mm mortar.

The sandbag fabric should be woven polypropylene. Each bag should have a nominal volume of 0.5 ft$^3$ and an approximate weight when full of 50 lb. The bags should be filled with washed sand, either dry or in saturated surface dry (that is, slightly moist) condition. Wet sand should not be used. Prefilled sandbags should be protected from the rain by storage on pallets, off the ground surface, and by covering them with a plastic tarpaulin or similar cover to prevent them from becoming saturated with water. The gradations and physical composition of the sand are not critical but it should be at least typical of local construction practice for sand used in foundations and backfill. Minor inclusions of clay or soils materials can be permitted. However, no rocks or stones should be placed in the sandbags. Typically, the sand used for the tests had a density of about 100 pounds per cubic foot and a moisture content of 6-7%.

Obviously, the five munition types do not cover all of the munitions that may be encountered. To determine the minimum wall and roof thickness for a particular shell other than those found in Table 5, the approach is as follows:

(1) Determine the initial fragment velocity ($V_F$) in ft/s, the maximum fragment weight ($W_F$) in pounds, and the kinetic energy ($W_F V_F^2/2$) in lb-ft$^2$/s$^2$ for the particular munition.

(2) Identify the munition with the next largest kinetic energy, from Table 6.

(3) Use the sandbag wall and roof thickness from Table 5 for the munition with the next largest kinetic energy shown in Table 6.

Table 6 provides the maximum fragment weight, the initial fragment velocity, and the resulting kinetic energy for the 5 munition types. The maximum fragment weight and the initial fragment velocity values were determined with the Mott and Gurney equations, as presented in TM 5-1300 [1] and detailed in HNC-ED-CS-S-98-1 [2].

Table 5 - Required Wall and Roof Thicknesses for Sandbag Enclosures, with Expected Sandbag Throw Distances and Pressures, for Five Tested Munitions

| Munition | Charge Weight, Comp B, lb | Required Wall and Roof Sandbag Thickness, in | Expected Maximum Sandbag Throw Distance, ft | Expected Peak Pressure @ 40 feet, psi | Expected Peak Pressure @ 80 feet, psi | Expected Sound Level @ 100 feet, dB |
|---|---|---|---|---|---|---|
| 155-mm M107 | 15.4 | 36 | 220 | 0.18 | 0.09 | 115 |
| 4.2-in M329A2 | 8.17 (TNT) | 24 | 125 | 0.16 | 0.06 | 116 |
| 105-mm M1 | 5.08 | 24 | 135 | 0.18 | 0.08 | 120 |
| 81-mm M374A2 | 2.1 | 20 | 125 | 0.14 | 0.05 | 119 |
| 60-mm M49A3 | 0.43 | 12 | 25 | 0.05 | 0.03 | 118 |

4.2-inch M329A2 mortar, the internal witness screens show no fragment penetrations deeper than about 18 inches. However, the thicknesses of 36 inches for the 155-mm M107 and 24 inches for the 4.2-inch M329A2 are retained for use in the field, since sandbag throw distances are based on these thicknesses. While possibly thicker than necessary from capturing fragments, the increased total mass of the sandbags results in reduced sandbag throw distances.

Detailed descriptions of all tests and results are provided in "Evaluation of Sandbags for Fragment and Blast Mitigation" by Southwest Research Institute [3].

## 3.0 Guidelines for Use of Sandbags

### 3.1 Enclosure Geometry

Table 5 summarizes the results of the tests. This table specifies the minimum thickness of sandbag walls and roof that is needed to completely contain the fragments for the five munitions that were tested in this project. It also gives the expected maximum sandbag throw distances, the peak pressures at 40 feet and 80 feet, and the sound level at 100 feet, for the five munitions. For safety and conservatism, the expected sandbag throw distances are approximately 10% larger than the largest distances actually measured in the tests. Thus, the expected sandbag throw distances given in Table 5 are conservative in two ways: first, the largest measured sandbag throw distance from all tests of a particular round is used and second, this value is increased by 10%. Due to the already low values of peak pressures, a similar increase in the expected peak pressures was not deemed necessary or justified.

Table 4 – Summary of Results from Comprehensive Explosive Tests

| Munition | Sandbag Thickness (in) to Defeat Fragments | Max. Sandbag Throw Distance (ft) | | Max Peak Overpressure (psi) @ 40 ft | | Max Peak Overpressure (psi) @ 80 ft | | Max Noise Level (dB) at 100 ft |
|---|---|---|---|---|---|---|---|---|
| | | Side of Round | Nose/Tail of Round | Side of Round | Nose of Round | Side of Round | Nose of Round | |
| 155-mm M107 | 36 | 200 | 130 | 0.06 | 0.12 | 0.04 | 0.05 | 114.7 |
| 4.2-in M329A2 | 24 | 110 | 70 | 0.12 | 0.14 | 0.04 | 0.06 | 115.8 |
| 105-mm M1 | 24 | 120 | 50 | 0.17 | 0.18 | 0.07 | 0.08 | 119.3 |
| 81-mm M374A1 | 20 | 110 | 30 | 0.14 | 0.08 | 0.05 | 0.03 | 118.3 |
| 60-mm M49A3 | 12 | 20 | 20 | 0.06 | 0.08 | 0.02 | 0.03 | 117.3 |

Pressure gages, a sound meter, high speed cameras, digital cameras and video cameras were used for data acquisition during each test. Internal and external witness screens were used to determine how deeply the fragments moved into the sandbag mass and whether any fragments exited the sandbag enclosure.

Table 3 – Test Matrix for Comprehensive Explosive Tests

| Test No. | Orientation | Standoff, in. | | | | | Wall Thickness, in. | | | | Wall Height, in. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_R$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $H_1$ | $H_2$ |
| 155-5 | Horizontal | 7 | 7 | 5 | 6 | 7 | 36 | 36 | 36 | 36 | 13 | 36 |
| 4.2-1 | Vertical | 5.5 | 5.5 | 5.5 | 5.5 | 6 | 20 | 24 | 31 | 36 | 19 | 24 |
| 4.2-2 | Horizontal | 6.5 | 6.5 | 6 | 6 | 7 | 24 | 25 | 24 | 24 | 11 | 24 |
| 4.2-3 | Horizontal | 6 | 5 | 5 | 6 | 7 | 24 | 25 | 25 | 24 | 11 | 24 |
| 105-1 | Vertical | 5.5 | 5.5 | 5.5 | 5.5 | 6 | 20 | 26 | 31 | 35 | 25 | 24 |
| 105-2 | Vertical | 0 | 0 | 4 | 6 | 6 | 29 | 25 | 19 | 25 | 26 | 23 |
| 105-3 | Horizontal | 7 | 5 | 5 | 5 | 9 | 24 | 24 | 24 | 24 | 13 | 24 |
| 105-4 | Horizontal | 6.5 | 6 | 5 | 6 | 7 | 25 | 25 | 24 | 24 | 11 | 23 |
| 81-1 | Vertical | 5 | 5 | 6 | 6 | 6 | 12 | 19 | 23 | 30 | 15 | 18 |
| 81-2 | Horizontal | 7 | 6 | 5.5 | 7 | 6 | 18 | 24 | 18 | 24 | 9 | 18 |
| 81-3 | Horizontal | 7 | 6 | 5 | 6 | 7 | 18 | 19 | 18 | 19 | 10 | 18 |
| 81-4 | Horizontal | 6 | 5.5 | 5.5 | 5.5 | 8 | 19 | 20 | 19 | 20 | 11 | 18 |
| 60-1 | Vertical | 6 | 6 | 6 | 6 | 6 | 13 | 19 | 23 | 30 | 11 | 12 |
| 60-2 | Horizontal | 6.5 | 3 | 5.5 | 3 | 6 | 12 | 12 | 12 | 12 | 8 | 13 |

All detonations were high order and results were obtained. The assorted witness screens were scattered across the site. Where possible, each screen was identified and photographed and the number of fragment holes or the condition of the screen was recorded. Sandbag throw distances were recorded in 10 foot increments from ground zero to the furthest sandbags. Blast overpressures were recorded for all tests at 40 feet and 80 feet from ground zero. A digital sound meter was placed 100 feet from ground zero. A summary of the results is shown in Table 4.

The final test for each munition was a confirmation test. These included tests 155-5, 4.2-3, 105-4, 81-3 and 60-2. The purpose of the confirmation tests was to model as closely as possible the actual use of sandbags in field conditions. In each test the internal witness screens were omitted. Sandbags were staggered both horizontally and vertically. External witness screens were placed over the roof and the two sides facing away from the pressure gages. After each test, the external witness screens were recovered and inspected for fragment penetrations. No such penetrations were identified. Therefore, the sandbag thicknesses defined in Table 4 are those used in the confirmation tests. For two munitions, the penetration data from internal witness panels suggests that somewhat smaller sandbag thicknesses may be sufficient to capture all fragments. As stated above for the 155-mm M107, internal witness screens show no fragment penetrations for sandbag thicknesses of about 24 inches or more. For the predicts that 24 inches of sand will stop the design fragment from the 155-mm M107 projectile.

Sandbag throw distances were recorded in 10 foot increments from ground zero to the furthest sandbags. The maximum sandbag throw distances were 150 feet, 191 feet, 157 feet, and 150 feet for tests 1 through 4, respectively. All of the furthest thrown sandbags came from the roof. In most cases, the roof sandbags were found relatively intact while the wall sandbags were often disintegrated. The bulk of the sandbags fell within 100 feet with only a few beyond this distance. An examination of the sandbag throw distances show that the standoff, the size of the bag, and the weapon orientation did not affect the throw distance to any significant degree.

Blast overpressures were recorded for all 4 tests (see Table 2). As shown, the sandbag enclosures greatly reduced the magnitude of the pressure. In test 3, a digital sound meter was placed 100 feet from ground zero and the maximum sound level recorded was 114.7 decibels.

Table 2 – Blast Overpressures from Preliminary Explosive Tests

| Test No. | Side 1 | | | | Side 4 | | | |
|---|---|---|---|---|---|---|---|---|
| | P1 @ 40', psi | P2 @ 40', psi | P3 @ 80', psi | P4 @ 80', psi | P5 @ 40', psi | P6 @ 40', psi | P7 @ 80', psi | P8 @ 80', psi |
| 155-1 | 0.67 | 0.71 | ND | ND | 0.37 | 0.38 | ND | ND |
| 155-2 | 1.31 | 1.18 | ND | ND | 0.74 | 0.97 | ND | ND |
| 155-3 | 0.16 | 0.16 | 0.07 | 0.06 | 0.16 | 0.18 | 0.09 | ND |
| 155-4 | 0.04 | 0.04 | 0.03 | 0.03 | 0.07 | 0.08 | ND | 0.05 |

ND = no data

## 2.3 Comprehensive Explosive Tests

An additional fourteen tests were performed: one more using 155-mm M107 projectiles, four using 105-mm M1 projectiles, three using 4.2-in M329A2 projectiles, four using 81-mm M374A2 mortars, and two using 60-mm M49A3 mortars. The test matrix for the comprehensive explosive tests is shown in Table 3. For all tests performed with the munition in the vertical orientation, detonation was achieved using a donor charge of 100 grams (50 grams for test 60-1) of C-4 in the fuze well. For all tests performed with the munition in the horizontal orientation, detonation was achieved using a well perforator. TOA pins were used for all tests to check if a high order detonation was achieved.

For each of the comprehensive explosive tests, woven polypropylene 0.5 $ft^3$ sandbags were filled with 50 lbs of washed river sand. The sandbags were painted and numbered as described in Section 2.2 to indicate their original position in the sandbag enclosure. Moisture content was not controlled nor monitored during the test program.

Detailed descriptions of all tests and results are provided in "Evaluation of Sandbags for Fragment and Blast Mitigation" by Southwest Research Institute [3].

Table 1 – Test Matrix for Preliminary Explosive Tests

| Test No. | Orientation | Standoff, in. $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_R$ | Wall Thickness, in. (Bag Size) $T_1$ | $T_2$ | $T_3$ | $T_4$ | Wall Height, in. (Bag Size) $H_1$ | $H_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 155-1 | Vertical | 12 | 6 | 6 | 12 | 6 | 32 | 32.5 | 45 | 43 | 32 | 20 |
| 155-2 | Vertical | 6 | 6 | 6 | 6 | 6 | 18(s) | 54 | 18(s) | 53(s) | 32 | 22 |
| 155-3 | Horizontal | 6 | 6 | 6 | 6 | 6 | 30 | 48 | 24 | 24 | 12 | 30 |
| 155-4 | Horizontal | 6 | 6 | 6 | 6 | 6 | 35 | 36 | 34 | 36 | 12 | 36 |

Note: All walls were constructed with large bags, except for those designated with an "s" for small bags.

### 2.2.1 Preliminary Explosive Test Results

For tests 1 and 2, the 155-mm M107 projectile was detonated using a donor charge of 200 g of C-4 placed in the fuze well and initiated with an Exploding Bridge Wire. For tests 3 and 4, the 155-mm M107 projectile was detonated using a well perforator shaped charge. This approach is typically used for on-site detonations. Time of arrival (TOA) pins were used for all tests to determine if a high order detonation was achieved.

All detonations were high order and results were obtained. The make screens and their frames and the assorted witness screens were scattered across the site. Where possible, each screen was identified and photographed and the number of fragment holes or the condition of the screen was recorded. The results of the first three tests suggested that a wall and roof thickness of 36 inches should be sufficient to contain all of the fragments and to reduce the overpressure levels. The dimensions of test 4 confirmed this configuration.

From the limited data collected on standoff distance, it appears that for standoffs of 6 and 12 inches there is no difference in the thickness of sandbags required to stop fragments. Test 2 showed that the size of the sandbag did not affect the fragment penetration. Test 3 showed that the horizontal orientation of the munition did not greatly effect the fragment penetration. Tests 3 and 4 showed that the base plate of the munition broke up and was stopped by 24 inches or less of sandbags.

The data collected showed that approximately 20 inches of sandbags will completely contain the fragments from the 155-mm M107 projectile. The only indications of fragments exiting the sandbag enclosure came from the two identical 18 inch walls of test 2 (external witness screens on sides 1 and 3 both registered fragment impacts). Internal witness screens at depths of 20 inches to 24 inches for all 4 tests did not indicate any fragment impacts. In tests 2 through 4, the roof witness screens also showed no penetrations for 20 to 36 inches of roof depth. The CONWEP software [4] occur it is necessary to reduce the coupling between the explosive charge and the surrounding soil. This coupling is dependent on the separation distance between the charge and the soil. Full coupling implies that the maximum amount of energy, or velocity, is transferred from the explosive into the soil immediately adjacent to the charge. If an explosive charge is placed in a cavity, so that an air gap exists between the charge and the walls of the cavity, coupling between the explosive and soil is reduced. Therefore, a standoff of some distance is required to reduce the coupling effect. Calculations to determine the velocity of sand particles from a buried explosion were performed. The velocity of the sand particles was compared to the velocity of the design fragment through sand. These calculations suggest that at a distance between 6 and 12 inches from the explosion, the fragment velocity exceeds the particle velocity. Therefore, the initial standoff distances for the tests were 6 and 12 inches.

## 2.2 Preliminary Explosive Test Phase

In the preliminary explosive tests, four tests of statically detonated 155-mm M107 projectiles were performed. These tests provided the data needed to specify the amount and configuration of sandbags that are required to safely detonate a 155-mm projectile in place, verified that the general test procedure was satisfactory, and defined the instrumentation and data acquisition systems for the subsequent comprehensive explosive tests. Figure 1 shows the site layout for the tests of sandbag enclosures. Although, munitions are rarely oriented vertically for demolition in place, the vertical orientation provided the opportunity to evaluate a greater number of combinations of wall thicknesses and standoff distances. Figures 2 and 3 show the sandbag enclosure configurations for vertical and horizontal weapon tests.

The test matrix for the preliminary explosive tests is shown in Table 1. Two tests were run with the 155-mm in the vertical orientation and two in the horizontal orientation. Each test allowed five standoff distances and five sandbag thicknesses to be evaluated.

The sandbags were made of woven polypropylene, as is commonly used by explosives and ordnance disposal (EOD) personnel, and the volume/weight of the sandbags was either 0.5 $ft^3$/50 lbs for the large bags or 0.25 $ft^3$/25 lbs for the small bags. The small bags were used for test two. No additional information was provided by using the small bags so these were not used for any other tests. The bags were filled with a "washed river" sand that was judged to be "typical" by a local soil consultant (Fugro-McClelland Southwest, Inc.).

To determine the sandbag throw distribution some of the sandbags in the first two tests were filled with sand colored with dye. The dye did not improve the quality of the test results. Spray paint was used in the subsequent tests to mark each bag with its original position in the sandbag enclosure. A different color was used to indicate the wall or the roof and numbers were used to indicate the layer in which the sandbag was located.

## LIST OF FIGURES